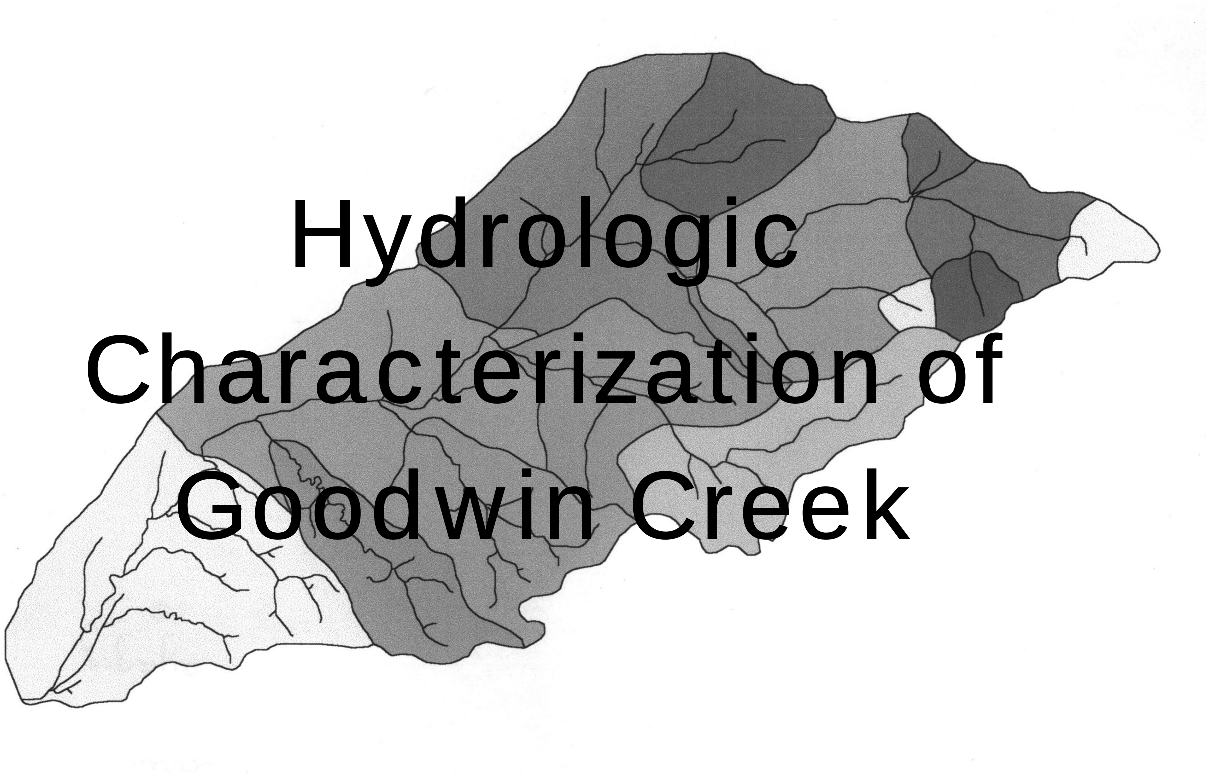
ENGINEERING RESEARCH AND DEVELOPMENT CENTER

United States Army Corp of Engineers

Hydrologic Characterization of Goodwin Creek



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ABSTRACT

Goodwin Creek streamflow data was used to develop and test a hydrologic model designed to predict streamflows at un-gauged basins within the Yazoo River Basin region. Flow duration curves (FDCs) were generated for the thirteen sub-basins that comprise the Goodwin Creek watershed. The resulting FDCs were adjusted to fit a one-parameter exponential distribution. The parameters obtained from this type of distribution were related to geomorphic features of the sub-basins. Drainage area was found to be the most adequate attribute to predict such parameters. The similarity between observed and predicted flow duration curves for an experimental sub-basin validated the capability of the model for estimating streamflows.

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I. Introduction

The Demonstration Erosion Control (DEC) program was authorized in 1984. This project intended to create alternatives to control streambank erosion, sedimentation and flooding on the Yazoo River Basin, Mississippi. Several agencies are working together to accomplish this task. These are the US Army Corp of Engineers (USCOE), Vicksburg District; the Natural Resources Conservation Service (NRCS); the USDA Agricultural Research Service (ARS); and the US Army Engineering Research and Development Center (ERDC) (previously called the Waterways Experiment Station (WES)). An experimental watershed within the Yazoo River basin was selected in order to test the models developed under this program. The Goodwin Creek watershed fulfilled the requirements established in the selection process.

This hydrologic characterization of the Goodwin Creek watershed in Mississippi is the first phase of an extended research work that will be conducted on this basin. The long-term results of the DEC project will provide practical methods to control and reduce the sediment yield and streambank erosion problems. This report introduces a regional hydrologic model for application at un-gauged watersheds where such problems are confronted.

The objective of the present study was to perform a preliminary hydrologic analysis of the Goodwin Creek streamflow record. The specific objectives were to perform a statistical analysis of the data and to attempt to develop a prediction model which could be applied to similar basins within the region.

In the hydrologic analysis, streamflow data was used to generate flow duration curves (FDCs) for thirteen sub-basins comprising the Goodwin Creek watershed. A FDC is a graphical representation of the exceedance probability for a given streamflow value over a determined period of time. These FDCs were adjusted to fit a one-parameter exponential distribution. The parameters obtained from this distribution were related to geomorphic parameters of the sub-basins. The drainage area was found to be the most adequate attribute in a relationship with the exponential distribution parameter.

The resulting hydrologic model, developed to predict streamflows at ungauged sites, only requires the estimation of the basin drainage area. This characteristic is either available for most watersheds or can be easily computed from topographic survey maps. Discharge data from one sub-basin was excluded from the analysis in order to test the procedure. The similarity between observed and predicted flow duration curves for the experimental sub-basin validated the capability of the model for estimating the flow duration curve.

II. Literature Review

A great deal of the information associated with Goodwin Creek was obtained from Research Report No. 3 USDA-ARS (Blackmarr, 1995). The United States Department of Agriculture (USDA) is one of the agencies in charge of the monitoring and evaluation of the DEC project. Research Report No.3 documents the hydrologic data gleaned on the creek between 1982 and 1993. However, the present study used runoff data from October 1981 to September 1999. In addition to runoff, other data recorded for this basin are: sediment production, rainfall, land use, soil characteristics, topography, water temperature and climatologic parameters. Research Report No.3 also includes other important facts related to the data acquisition systems, their design, location and operation. The forum article by Alonso and Bingner (2000) was used as another source of information on Goodwin Creek general characteristics.

Of particular interest to the development of the model are publications related to the application of statistical tools to analyze discharge data. Relevant studies are those that focused on the use of Flow Duration Curves, such as the work of Fennessey and Vogel (1990, 1994) and Vogel and Fennessey (1995). Other important papers for the study are Vogel and Wilson (1996), and Vogel et al. (1999).

Fennessey and Vogel (1990) published a study on a regional FDC model developed for 23-gauged basins in Massachusetts. A lognormal probability distribution function was fitted to the mean daily flow duration data, which was then regionalized by relating distribution parameters to geomorphic variables. Drainage area and relief proved to be the best predictors of the distribution parameters. The model represents a practical application of FDCs to estimate river discharges at climatologically similar sites lacking a monitoring and data collection program.

Rasmussen and Perry (1997) also derived an equation to predict streamflows for un-gauged sites in Kansas; using regression methods. The resulting regression model needs the estimation of the drainage area, the mean annual precipitation, soil permeability, and the slope of the main channel in a river. The results of the latter study are not as accurate as the results obtained in the probability model developed by Vogel and Fennessey. Afterward, Vogel, Wilson and Daly (1999) extended the regional regression models application to 1,553 unmonitored watersheds across the United States where hydrologic, geomorphic and climatic characteristics are known. The relations established with the regression analysis were remarkably precise.

In a further treatment of the subject, Fennessey and Vogel (1994) proposed different methods for constructing FDCs, arguing that the curves should be interpreted only for the period of record used to construct them. Also, they developed confidence bands for FDC models.

In a separate work (Vogel and Fennessey, 1995), they discussed the application of FDCs to water resource planning issues such as water quality, hydropower, flood control and sedimentation, among others. A rating curve that describes the relationship between the streamflow and certain water resource index is combined with a FDC to produce the water resource index duration curve. The interpretation of the resultant curve depends on the method used to construct it.

Vogel and Wilson (1996) developed L-moment diagrams for maximum, minimum, and average streamflow values recorded in approximately 1,455 rivers of the United States. They found that three distributions: the generalized extreme value (GEV), the three-parameter lognormal (LN3), and the log Pearson Type III (LP3), are useful for predicting the maximum streamflow values. Minimum and average streamflows were better fitted with the LP3 distribution.

Later publications, such as Vogel et al. (1999), focused on the practical approach of developing a regional regression model based on readily measured geomorphic and climate characteristics. This study uses data from 1,553 undeveloped watersheds of the United States. The derived model is intended to estimate annual runoff values at un-gauged watersheds for which other studies relating water supply, irrigation, hydropower, navigation, recreation, and water resources management are going to take place.

Procedures similar to the ones carried out previously were used in the development of the hydrologic model for the Goodwin Creek Watershed streamflow data.

III. Description of Study Area

The Goodwin Creek experimental watershed is located in North Central Mississippi, within an area known as Bluff Hills. Goodwin Creek flows into Long Creek, a tributary of the Yocona River (see Figure 1). It is part of the Yazoo River basin, with a total drainage area of 8.27 square miles.

The watershed can be divided into five different vegetative covers, three types of cultivated land (cotton, soybeans, and small grains), idle land, pasture, and forest. The main crops are cotton and soybeans.

The two major soil associations found in this watershed are the Collins-Falaya-Grenada-Calloway, and the Loring-Grenada-Memphis. The first group is classified as silty soils, poorly to moderately well drained, and are mainly located in the terrace and flood plain sites where much of the cultivated area is found. The other group comprises well-drained to moderately well-drained soils, generally found in the pasture and wooded area that developed on the loess ridges and hillsides of the watershed.

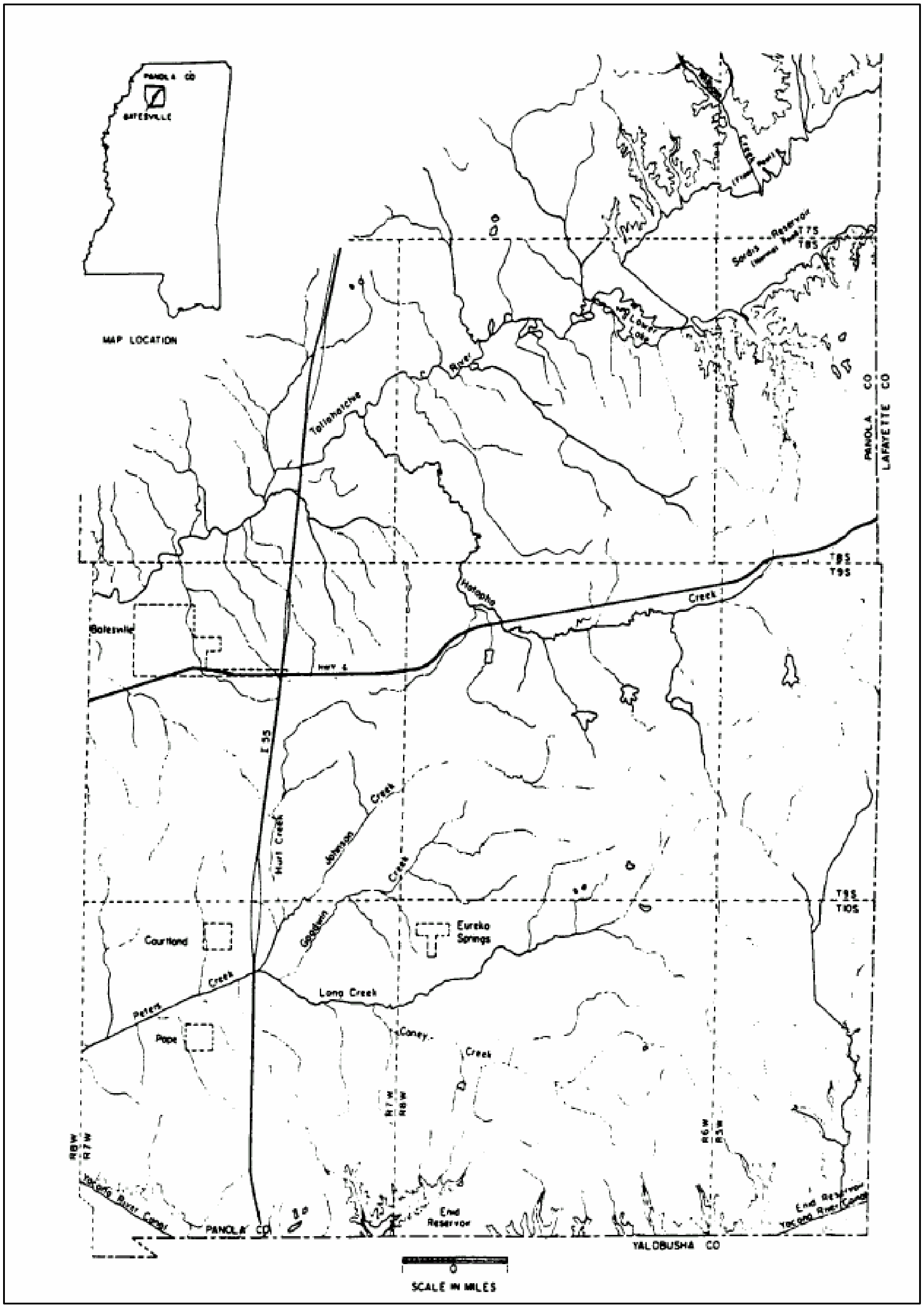

Figure 1. Location of Goodwin Creek– Panola County, Mississippi (Blackmarr, 1995)

The Goodwin Creek watershed is divided into fourteen individual sub-basins. Single drainage areas have been calculated to find the total drainage area that is contributing to each sub-basin. The accumulative areas found range from 0.06 to 8.27 square miles. Table 1 summarizes this data.

Table 1.
Sub-basin Areas for Goodwin Creek Watershed

Sub-basin	Sub-basin Area, A (mi^2)	Contributing Sub-basins	Cumulative Drainage Area, A_d (mi^2)
1	1.51	1-14	8.27
2	1.04	2-14	6.76
3	1.18	3,5,6,8-12	3.20
4	0.73	4,7	1.41
5	0.97	5,8-12	1.61
6	0.41	6	0.41
7	0.68	7	0.68
8	0.30	8,11,12	0.48
9	0.10	9	0.10
10	0.06	10	0.06
11	0.10	11	0.10
12	0.08	12	0.08
13	0.47	13	0.47
14	0.65	14	0.65

Flow-measuring flumes have been constructed at each of the sub-basin outlet points. They are equipped with data acquisition systems, recording and transmitting data on precipitation, flow stage, sediment samples, water temperature and other parameters. In addition, twenty-nine rain gages are evenly distributed within and just outside the drainage divide. See Figure 2 for a location map of the monitoring sites.

Watershed topography varies from small valleys to moderate hills. Terrain elevation above mean sea level ranges from 71 to 128 meters. The average channel slope is estimated to be 0.004.

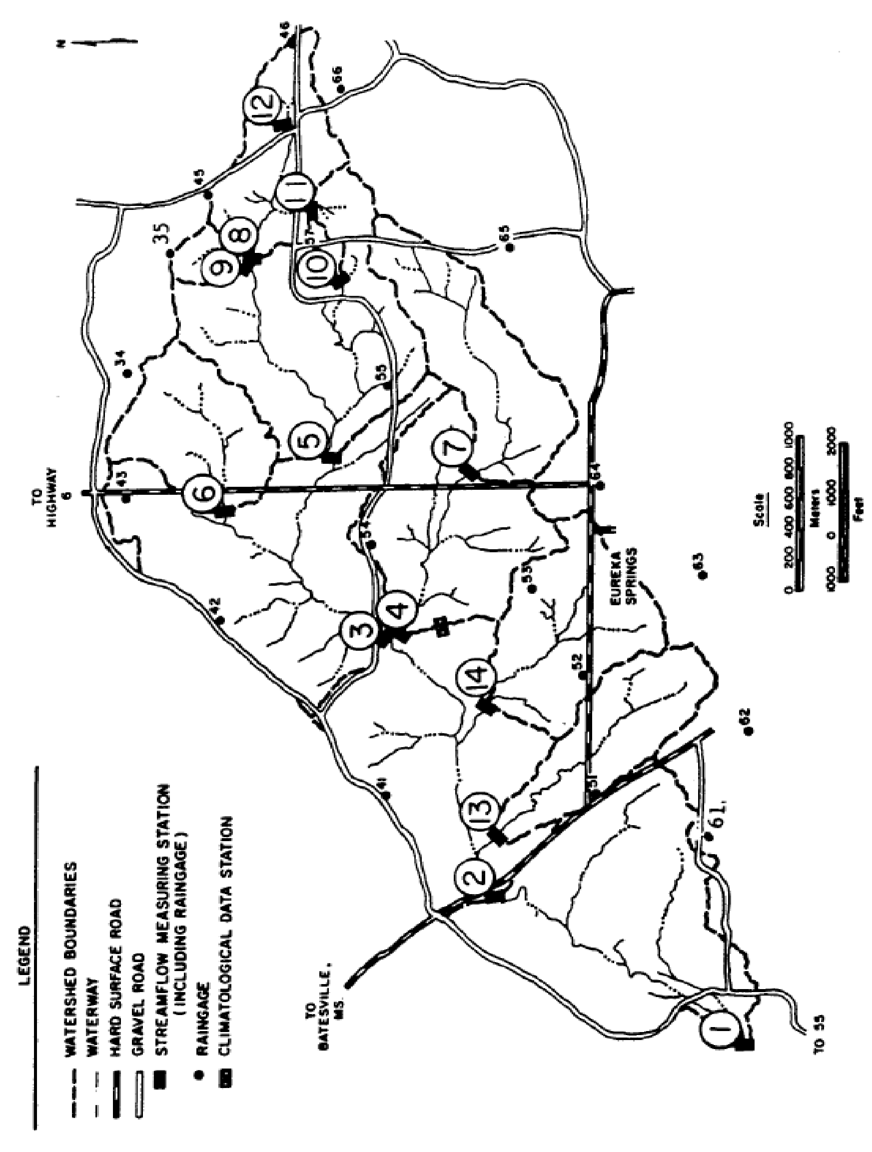

Figure 2. Goodwin Creek Experimental Watershed – Subdivision and Configuration (Blackmarr, 1995)

Other geomorphic attributes were measured from USGS digital elevation maps (DEMs). A DEM is the most common digital terrain elevation source. They were used in combination with the Watershed Modeling System (*WMS*) program **(SSG, 2000)** for delineation of the Goodwin Creek watershed and calculation of other basin parameters. Sub-basins were also demarcated and parameterized with WMS. The program is also capable of performing complete hydrologic analyses. A schematic of the watershed boundary trace as displayed by WMS is shown in **Appendix A**. Sub-basin identification numbers were assigned according to the gauging stations located at the watersheds outlets. The Goodwin Creek watershed stream network can also be observed in this figure. Parameter values for each sub-basin identified in Figure 2 are presented in Table 2.

Table 2.
Other Sub-basin Geomorphic Attributes for Goodwin Creek Watershed

Sub-basin ID	L_o[1] (ft)	S_o[2] (ft/ft)	L[3] (mi)	S[4] (mi/mi)	L_{ca}[5] (mi)	S_{ca}[6] (mi/mi)	L_c[7] (mi)	S_c[8] (mi/mi)
1	705.84	0.045	2.54	0.009	1.08	0.003	2.28	0.006
2	925.98	0.036	1.95	0.008	0.68	-0.001	1.71	0.002
3	666.34	0.036	1.95	0.010	0.67	0.005	1.67	0.008
4	588.39	0.038	1.72	0.009	0.56	0.007	1.49	0.009
5	671.59	0.036	1.66	0.011	0.58	0.005	1.35	0.007
6	570.64	0.030	1.17	0.016	0.64	0.012	0.90	0.012
7	690.03	0.029	1.92	0.011	0.80	0.006	1.60	0.009
8	694.65	0.032	0.99	0.013	0.44	0.008	0.71	0.007
9	565.09	0.040	0.56	0.023	0.21	0.011	0.31	0.014
10	717.78	0.035	0.34	0.022	0.06	0.028	0.06	0.028
11	759.55	0.029	0.42	0.016	0.10	0.010	0.11	0.013
12	1018.08	0.027	0.45	0.016	0.04	0.020	0.04	0.020
13	567.22	0.040	1.58	0.013	0.87	0.013	1.36	0.012
14	701.97	0.037	1.42	0.016	0.64	0.016	1.02	0.016

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[1] L_o = Average overland flow length
[2] S_o = Basin overland slope
[3] L = Basin length along main channel from outlet to upstream boundary
[4] S = Basin slope along main channel from outlet to upstream boundary
[5] L_{ca} = Length along main channel from outlet to point opposite centroid
[6] S_{ca} = Slope along main channel from outlet to point opposite centroid
[7] L_c = Maximum flow (watercourse) length
[8] S_c = Maximum flow (watercourse) average slope

Goodwin Creek was selected as the DEC project experimental watershed based on four factors. The first established that the experimental watershed should be located in the Bluff Hills area that drains into the Mississippi Alluvial Plain (See Figure 3). The second factor focused on the need of a watershed with a diversity of conditions allowing well-defined watershed subdivision. The third factor was a condition requiring a watershed that did not drain into an existing flood control reservoir. The final consideration was that the watershed should be close to the ARS-National Sedimentation Laboratory at Oxford, Mississippi, in order to facilitate the supervision and management of the monitoring operations.

Goodwin Creek watershed not only fulfilled selection requirements, but also exhibits most of the sedimentation and erosion problems afflicting various watersheds of the mid-continental and southeast areas of the United States.

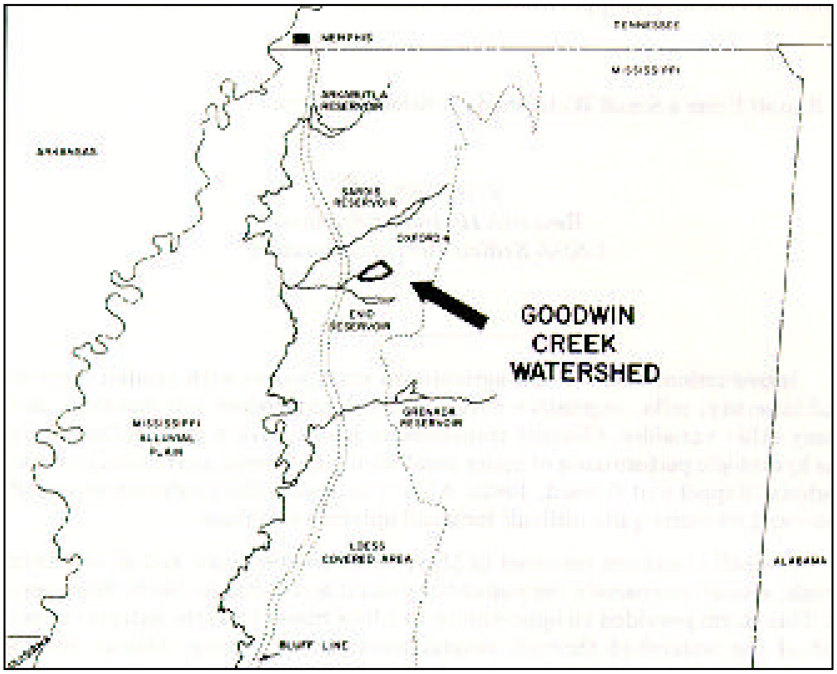

Figure 3. Mississippi Alluvial Plain (Dendy, 1983)

IV. Materials and Methods

A. Data Description

The streamflow data utilized for this investigation corresponds to a record period of eighteen years, from October 1981 to September 1999. Maximum monthly discharges were extracted from the continuous daily flows registered for the fourteen gauging stations located at the sub-basin outlets. Due to the vast amount of data obtained for each sub-basin, only a statistical summary of the discharge data is presented in this section for better appreciation. These are shown in Table 3.

As a consequence of some missing data, discharges for Sub-basin No. 10 were eliminated from the hydrologic model development. For completeness, however, statistical computations for this sub-basin are included in Table 2. It is expected that the exclusion of this sub-basin will not cause a remarkable difference in the results. Also, Sub-basin No. 10 contributes only 0.06 square miles to the total watershed drainage area.

Streamflow statistics for the remaining thirteen sub-basins are based on the monthly peak discharges for the total period of record of eighteen years. Tables in **Appendix B** present a detailed summary of flow statistics for each sub-basin calculated on a monthly basis. Three reasons contributed to the choice of monthly values: (a) the daily data showed a significant number of zero flow values - a not uncommon situation in creeks where perennial flow conditions do not exist or where very small flows are not recorded; (b) monthly data appeared more stable and less biased than daily data, partly for the reasons given in (a); (c) monthly values, although possibly exhibiting some seasonal correlation, can be more easily assumed to represent an independent series than daily values.

Table 3.
Statistics of Monthly Discharges (cfs) for Goodwin Creek Sub-basins
(October 1981 - September 1999)

Month	Average	Median	Standard Deviation	Maximum	Skewness	Skewness Coefficient	Kurtosis Coefficient	Variation Coefficient
1	789.0	514.1	934.6	5206.6	1.6E+09	1.96	4.55	1.18
2	716.5	478.4	829.2	4686.4	1.1E+09	1.87	4.32	1.16
3	496.8	277.2	787.5	5694.8	1.8E+09	3.78	17.80	1.59
4	221.6	137.7	268.4	1691.4	4.2E+07	2.15	6.42	1.21
5	261.7	145.1	323.8	1819.9	7.4E+07	2.17	5.93	1.24
6	92.1	54.8	115.4	592.8	3.0E+06	1.98	4.43	1.25
7	147.0	87.4	216.3	1346.4	3.1E+07	3.08	11.68	1.47
8	129.1	90.1	148.1	904.7	6.3E+06	1.94	5.16	1.15
9	25.4	16.4	29.8	196.8	5.2E+04	1.96	6.10	1.17
10[1]	2.7	0.5	4.7	28.1	2.5E+02	2.50	7.00	1.70
11	23.9	14.1	34.2	326.0	1.7E+05	4.19	29.41	1.43
12	47.9	26.3	107.3	1294.2	1.0E+07	8.29	87.90	2.24
13	78.1	46.3	107.5	720.8	3.9E+06	3.11	12.69	1.38
14	121.9	69.5	156.0	875.5	8.3E+06	2.20	6.15	1.28

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[1] Statistics based on a record period of 15 years, from October 1981 to September 1996.

An issue arose in the early stages of the study regarding the consideration of the skewness coefficient as a significant variable in the statistical analysis of flow data. Apparently, it had been observed that the skewness coefficient decreased significantly in the downstream direction for the lower sub-basins as these increased in catchment area. From Table 2 this pattern is not discernible. While some of the larger sub-basins do have lower coefficients than some of the smaller, upper ones, a definite pattern is not established. However, it may be that this happens when comparing independent watersheds. In the present case, it may be that the increase in variance obtained downstream of the confluence of correlated streams is much larger than the change in skewness, thus producing a lower skewness coefficient.

The variance will always increase in the downstream direction of the confluence of correlated tributaries. If, for example, tributaries X and Y join to form stream Z, such that Z = X + Y, then the variance of Z is related to the variances of X and Y by the relation Var[Z] = Var[X] + Var[Y] + 2Cov[X,Y]. That is, the variance of stream Z is larger than the sum of the individual variances of the tributaries by twice the covariance of the tributaries. Thus, the variance of the flow always increases in the downstream direction with respect to the variances of tributaries. If the flows in the tributaries are uncorrelated, then the covariance is zero. This is not the case with Goodwin Creek.

The coefficient of skewness, defined as the ratio between skewness (a signed variable) and the cube of the standard deviation (always positive), may well be decreasing in a downstream direction for correlated sub-basins as an effect of the downstream increase in variance with respect to that of the tributaries. The variance of the streamflow data for a sub-basin (X and Y) is calculated as the square of the standard deviation. Figures 4 and 5 show the skewness coefficient for each sub-basin and the standard deviation calculated for monthly peaks.

Also, as argued by Vogel and Fennessey (1995), product moment ratios, as the coefficient of variation and the skewness coefficient, provide almost no information about the probability distribution of daily streamflows. This is due to the highly skewed nature of daily streamflow series.

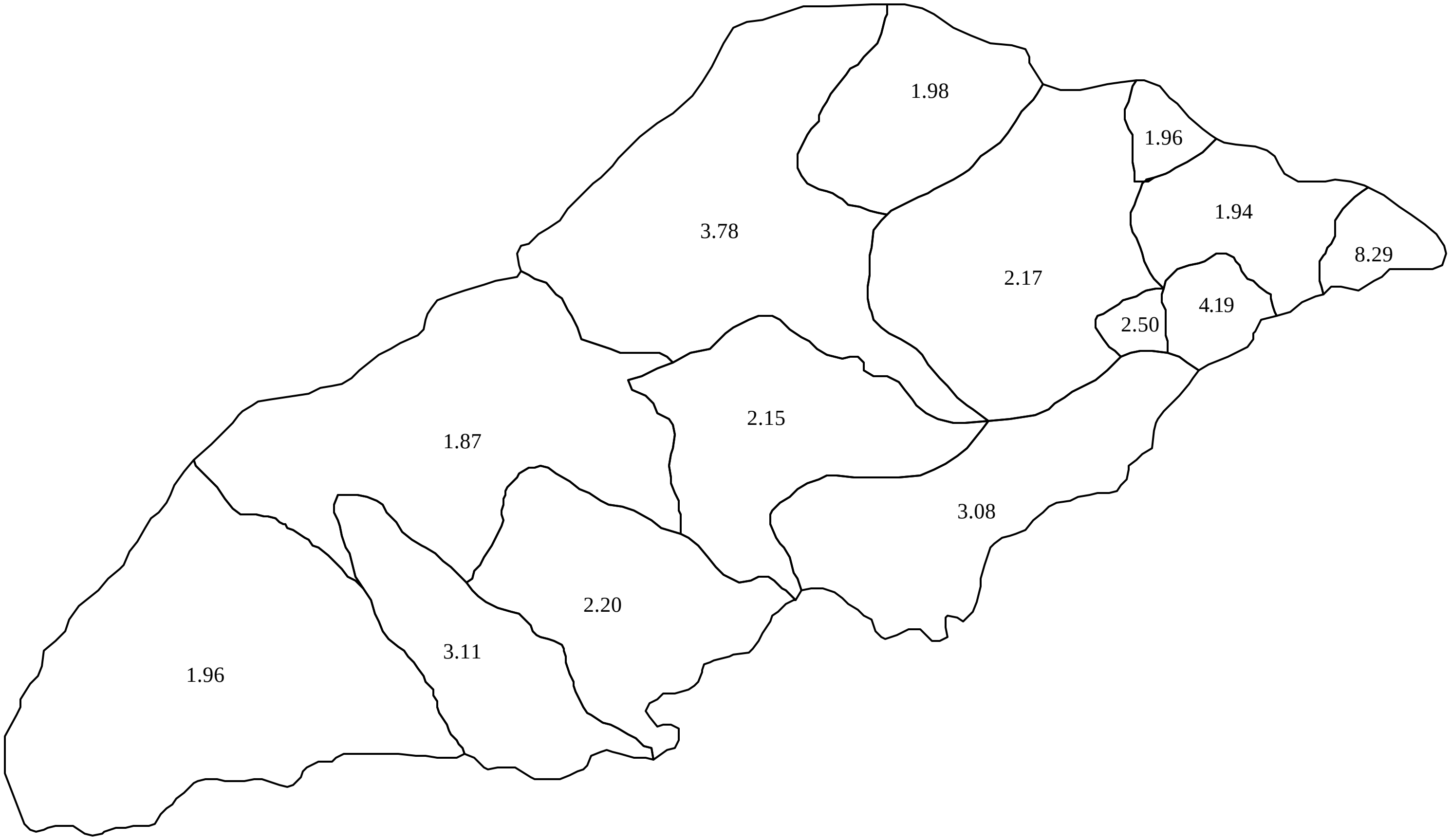

Figure 4: Skewness Coefficients for Goodwin Creek Sub-basins

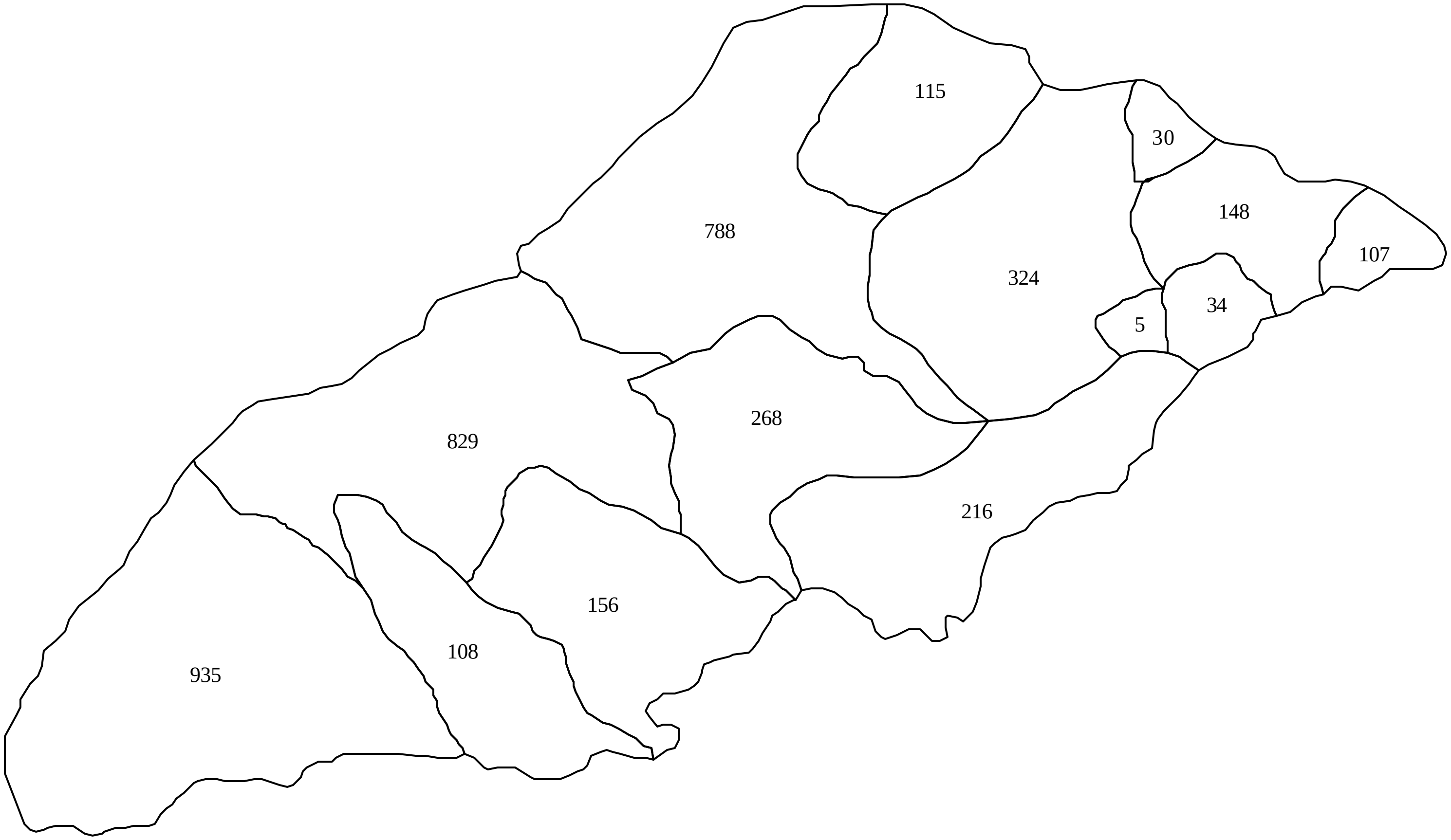

Figure 5: Standard Deviation for Goodwin Creek Sub-basins

B. Formulation of the Statistical Model

The first step in developing the model was the construction of streamflow duration curves for thirteen sub-basins. Most studies develop FDC graphs for daily streamflow; however, they can also be applied to maximum streamflow. Their interpretation will depend on the period of record on which they are constructed (Vogel and Fennessey, 1994). For the reasons discussed earlier, this study constructed monthly FDCs from a period of record of eighteen years.

The procedure consists of organizing streamflow values for each sub-basin in numerically descending order. An exceedance probability is assigned with a non-parametric plotting position formula, in this case the Weibull expression:

$$p = \frac{i}{n+1} \tag{1}$$

where,

i = streamflow number

n = number of observations (Total of 12 months x 18 years = 216 observations)

As an illustration, the resulting FDC for Sub-basin 2 is provided in Figure 6. Individual FDCs for all other sub-basins from Goodwin Creek are presented in **Appendix C**.

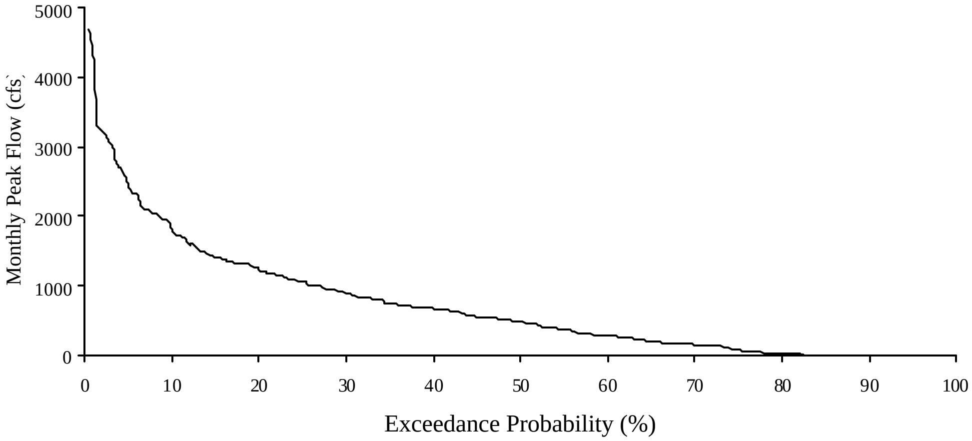

Figure 6. Streamflow Duration Curve for Sub-basin 2 Data

A cumulative probability function was fitted to the FDC for all sub-basins. Several distributions were considered, and the exponential distribution was found to be the one that better adjusted to the flow series. The fitting of the exponential distribution was accomplished with a statistical program. The adequacy of the fitting was examined visually by plotting the fitted curve on the flow data histogram. For Sub-basin 2, the relation is depicted in Figure 7. In this figure, the bars represent the sample flow frequency. The exponential distribution seemed to properly fit the sample histogram. However, a more quantitative examination was performed to test the adequacy of the distribution. The histograms for the other sub-basins are presented in **Appendix D**.

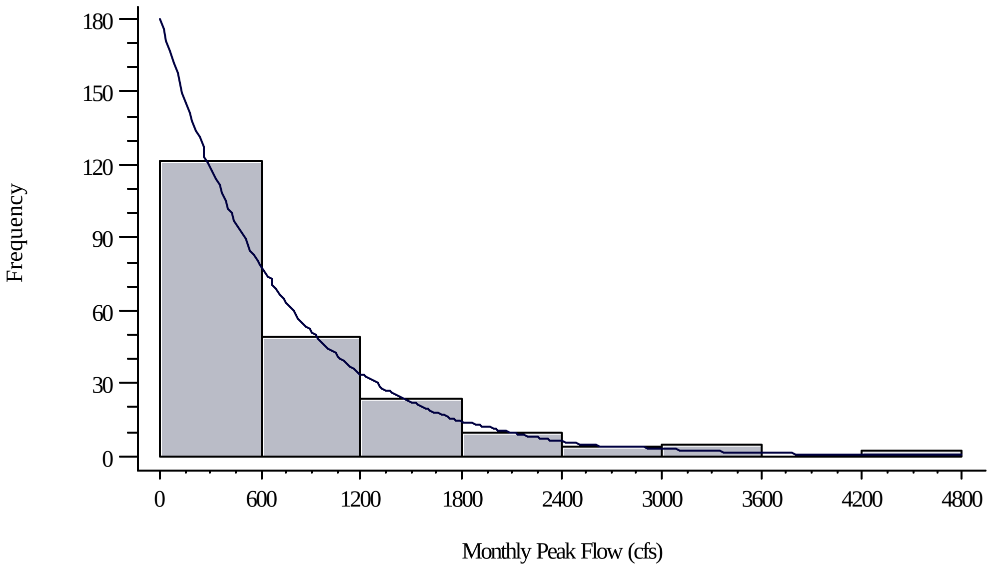

Figure 7. Frequency Histogram for Sub-basin 2 Streamflow Data with Fitted Distribution

The Chi-Square Goodness-of-Fit Test can be used to analyze the null hypothesis that the population distribution from which the flow data sample is drawn is the same as the hypothesized distribution. This is the most common test employed for this kind of comparative analysis. This methodology is intended to evaluate the observed frequency and the number of observations expected from the selected distribution for the same class intervals. A Chi-Square value can be calculated based on the observed and expected frequencies using the equation

$$\chi_c^2 = \sum_{i=1}^{k}(O_i - E_i)^2 \div E_i \qquad (2)$$

where,

k = number of class intervals

O_i = observed frequency

E_i = expected frequency (obtained from the exponential distribution)

The c_c^2 value estimated from the former equation must be smaller than a predetermined $c^2_{1-a,n}$ value so that the hypothesis that the data comes from an exponential distribution can be accepted. The predetermined values depend on the following variables:

1 -a = fixed confidence interval
n = degrees of freedom

$$v = k - p - 1 \tag{3}$$

where,

k = number of class intervals
p = number of parameters estimated from the distribution under study (one-parameter for the exponential distribution)

The outcome of the analysis showed that the monthly flow data for all thirteen sub-basins could be modeled by an exponential function with 95% confidence. The results of the statistical analysis are summarized in **Appendix E**.

The probability density function for the fitted exponential distribution, with parameter λ and flow variable x can be expressed as

$$f_x = \lambda e^{-\lambda x} \tag{4}$$

The cumulative exponential function represents the probability that $x = x_o$. This probability can be determined by integration of Equation 4.

$$F_x = P[x \leq x_o] = \int_0^{x_o} \lambda e^{-\lambda x} dx = 1 - e^{-\lambda x_o} \qquad (5)$$

Figure 8 depicts a representation of the probability density and the functions just described.

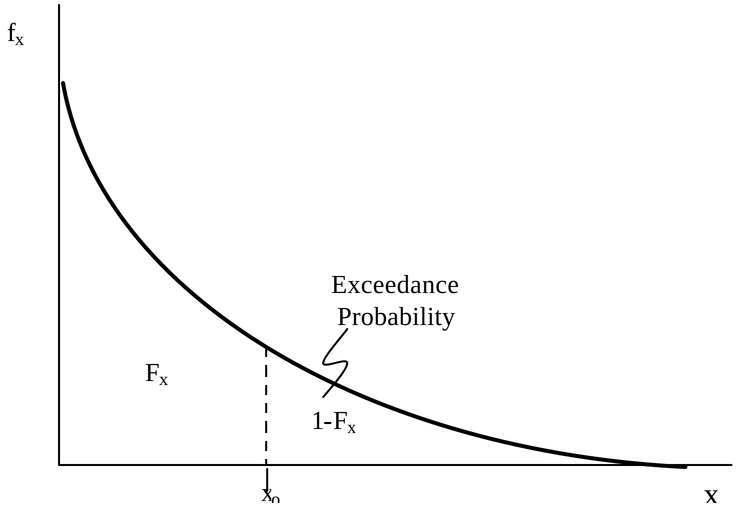

Figure 8. Exponential Density Function

Since the total area under a probability curve is unity, the probability that x ³ x_o could be obtained from

$$P[x \geq x_o] = e^{-\lambda x_o} \qquad (6)$$

where,

l = exponential distribution parameter

x_o = *variable value*

The parameter of the exponential distribution, *l*, can be estimated from the method of moments or the method of maximum likelihood, both yielding the following estimate:

$$\hat{\lambda} = \frac{1}{\overline{X}} \tag{7}$$

where,

$\overline{X}$ = *sample mean*

The notation will be slightly modified in order to describe the flow variable in a traditional fashion. Thus, the following is obtained:

$$P\left[q \geq q_p\right] = e^{-q_p/\overline{Q}} \tag{8}$$

where,

q_p = *monthly flow*

$\overline{Q}$ = *sample mean of flows*

An expression to predict q_p can be derived by taking the natural logarithm at both sides of Equation (8) and solving for the variable of interest. The monthly flow, q_p, is then estimated as

$$q_p = -\overline{Q} \times \ln\left[P\left(q \geq q_p\right)\right] \tag{9}$$

The monthly flow produced by a storm event with a specified exceedance probability can be computed from Equation (9). For un-gauged sites it will be impossible to apply the model unless an estimate of the mean flow is available. Furthermore, application of the model is restricted to climatologically similar sites. For such sites, the mean flow parameter can be estimated from a relation between the available mean flow sample and a geomorphic characteristic of the basin.

The mean flow sample set used to construct the FDCs was related to the computed geomorphic attributes of the sub-basins to identify the best possible fit. Amongst all the attributes tested, the drainage area was found to be the best predictor of the exponential parameter. **Appendix F** shows the relations obtained for other attributes.

A regression analysis was conducted in order to estimate the unknown parameter (response variable) in terms of the drainage area (independent variable). Pairs of mean flow and drainage area observations were plotted to find the mathematical equation that better predicted the parameter $\overline{Q}$. A power function gave the best fit. The results are depicted in Figure 9.

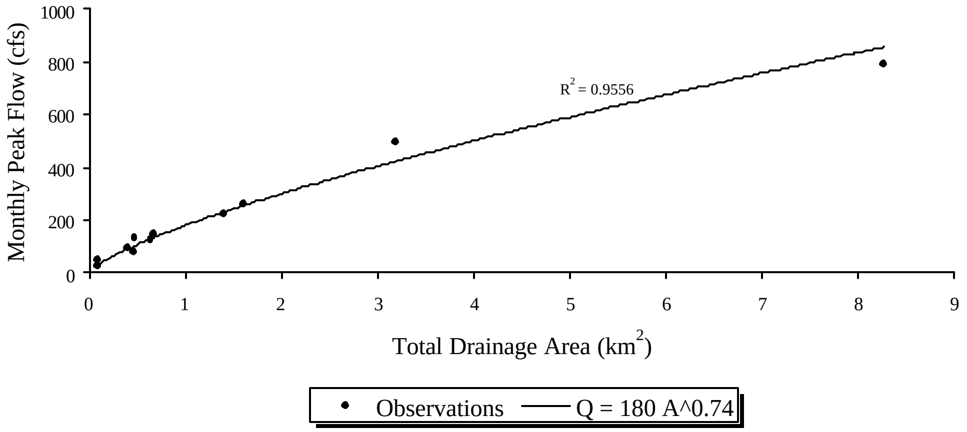

Figure 9. Regression Analysis Results on Mean Monthly Flow

The form of the regression equation is

$$\overline{Q} = cA_d^{\ b} \qquad (10)$$

where,

c, b = regression coefficients (180 and 0.74, respectively)

A_d *= drainage area of the basin (mi^2)*

The resulting mean flow will be in cfs units.

The acceptance of the regression model depends on the coefficient of determination, R^2, which results from fitting a line function to the data. In this case, the R^2 value obtained was 0.96. This number is significantly good considering that an R^2 equal to 1.0 indicates a perfect relationship between the response and the independent variables. This factor confirms that there is a strong power relationship, mathematically speaking, between the mean flows and the drainage area of the basins.

The equation to calculate the exponential distribution parameter can be substituted in the expression derived to predict the monthly flow. This results in

$$\hat{q}_p = -\left(180\,A_d^{\ 0.74}\right) \times \ln\left[P\left(q \geq q_p\right)\right] \qquad (11)$$

The hydrologic model is then complete. It only requires an estimate of the drainage area for estimating the monthly flow. Needless to say, the use of Equation (11) will be meaningful only for a watershed climatologically similar to Goodwin Creek.

V. Discussion

Validation of the model involves a comparison between predicted and observed monthly flows. A monitored basin would be needed to perform the comparison. Due to the unavailability of such information at present, a gauged sub-basin of the Goodwin Creek watershed was chosen for the comparison. To do this, the sample data from Sub-basin 2 was excluded from the regression analysis. Station 2 is one of the two routing experimental stations selected within the Goodwin Creek watershed. Station 1 is the other streamflow routing testing site, and is located at the outlet of the watershed. Sub-basin 1 data was included in the regression analysis.

The model must be critically examined for suitability of application. Equation 11 must be employed on the testing sub-basin data in order to compare the observed and predicted FDC. The drainage area of Sub-basin 2 is about 6.76 mi^2. Using this area and varying the value of the exceedance probability, the predicted FDC is obtained. Observed and predicted FDCs are compared in Figure 10:

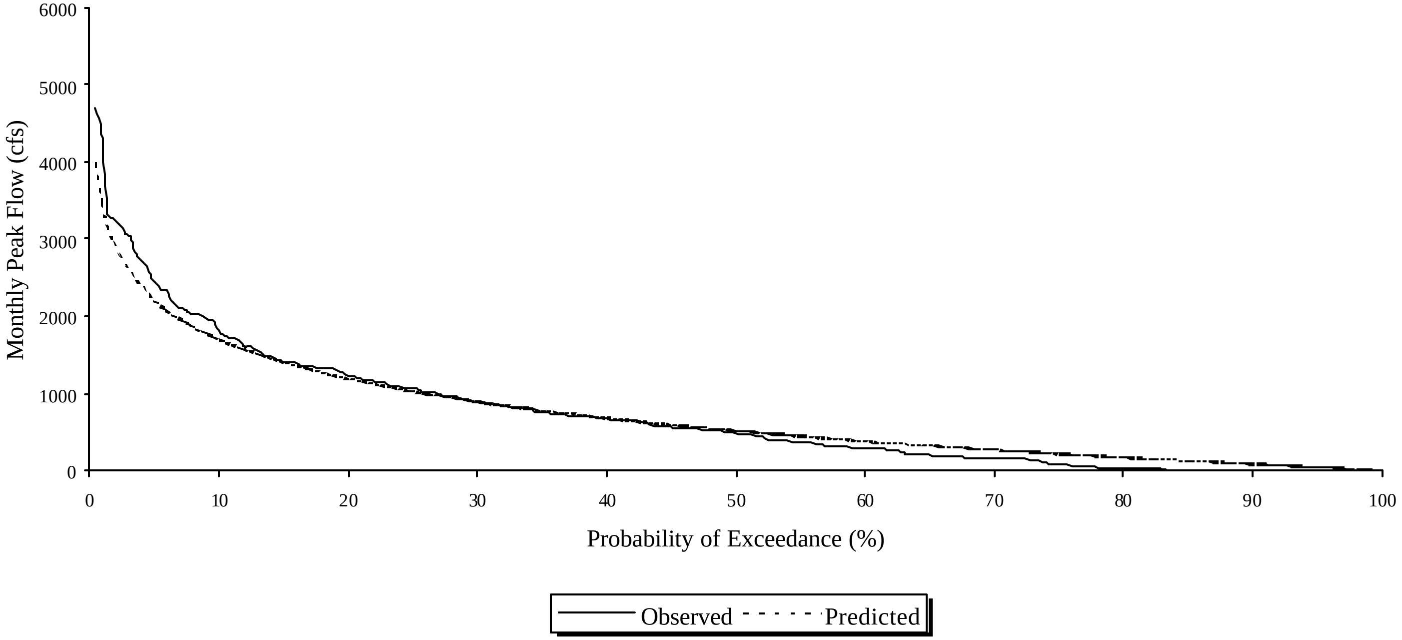

Figure 10. Comparison of Observed and Predicted FDCs for Sub-basin 2

Although the resultant model seems to be a good predictor of the FDC, a diversity of uncertainties could be affecting the results. The most salient of the uncertainties are those related to the fact that the sub-basin flows are correlated since they arise out of the same hydrologic unit. Further research could be needed to assess the bias and loss of degrees of freedom introduced by this fact, and whether such effects are relevant for the purposes of the model.

The significance of the deviation between the actual and predicted FDC can be estimated by developing confidence intervals. Figure 11 shows the compared FDCs with the attendant 95% lower and upper confidence bands. The empirical FDC obtained from the flow record lay just outside the lower confidence limit for exceedance probability values somewhat greater than 70%. Nevertheless, the difference is insignificant and can be neglected. Vogel and Fennessey (1994) concluded that a FDC is highly sensitive in its lower tail. The interest would lie mainly in the low-exceedance probability values, and these are within the limits.

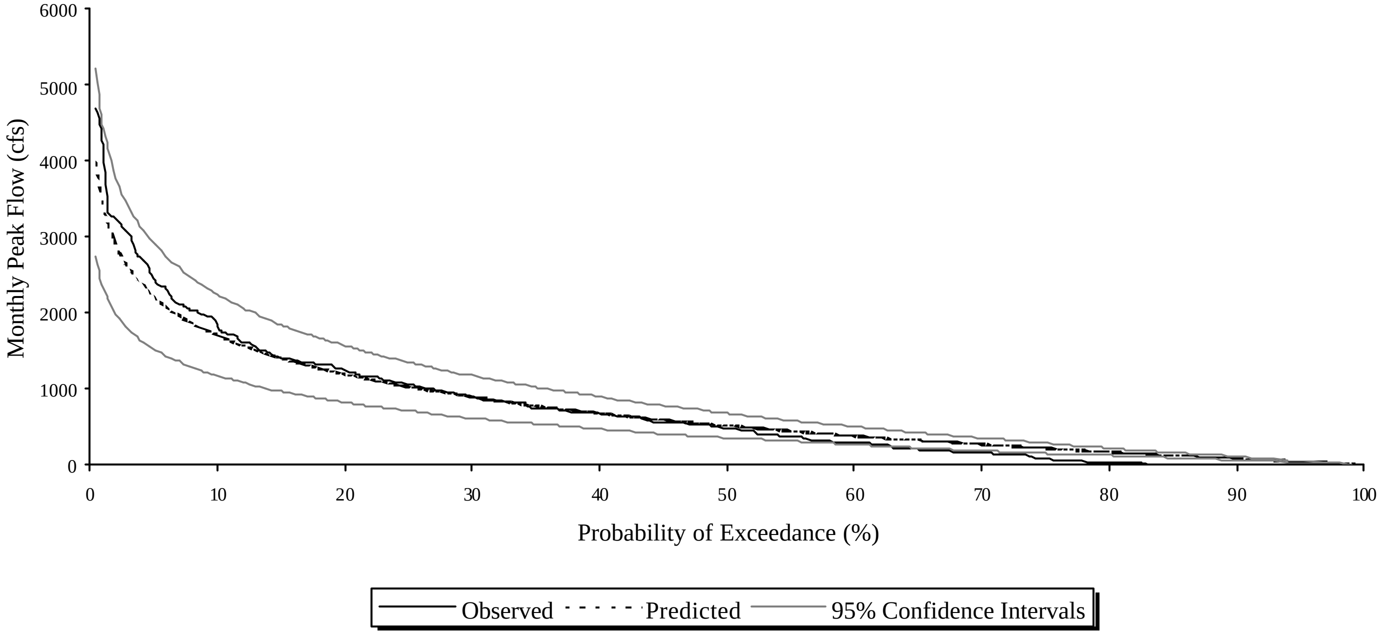

Figure 11. Confidence Intervals for Predicted FDC

The procedure derived to compute the confidence bands for the proposed model is developed in **Appendix G**. The confidence bands can be expressed as

$$\hat{q}_p \pm t_{1-\alpha/2,\nu} \sqrt{\mathrm{VAR}\left(\hat{q}_p\right)} \qquad (12)$$

where,

$\hat{q}_p$ = *predicted flow*

$t_{1-a/2,n}$ = *t distribution value (2.23)*

The parameter a is 0.05 for a 95% confidence interval. In this case, the degrees of freedom, n, can be obtained from

$$\nu = m - p \qquad (13)$$

where,

m = number of sub-basins used to estimate the regression Equation (12)

p = number of regression model parameters (c and b)

Thus, the value of the *t* distribution that will be used to set the limits of the 95% confidence intervals will be $t_{0.975,10}$ = 2.23.

The variance of the predicted flows was estimated as

$$\mathrm{VAR}\left(\hat{q}_p\right) = \ln^2\left[P\left(q \geq q_o\right)\right]\left(\overline{Q} \ln 10\right)^2 \mathrm{VAR}\left(\log \overline{Q}\right) \qquad (14)$$

Equation 12 can be rewritten as

$$\hat{q}_p \pm 2.23\sqrt{\ln^2\left[P\left(q \geq q_o\right)\right]\left(\overline{Q}\ln 10\right)^2 \mathrm{VAR}\left(\log \overline{Q}\right)} \tag{15}$$

Equation (15) was used to estimate the 95% confidence limits on the predicted FDC.

VI. Conclusions

This study developed Flow Duration Curves (FDCs) for the monthly flows of Goodwin Creek in Mississippi. The curves were developed by fitting exponential distributions to the monthly flow series for each tributary sub-basin in Goodwin Creek. A regionalized FDC model was developed, relating distribution parameters to geomorphic variables. Geomorphic variables were computed with the Watershed Modeling System package. Of the variables tested, the best overall fit was obtained with the drainage area, yielding a power relationship between model parameter and area. The relation can be used to generate an FDC for an un-gauged stream only for climatologically similar watersheds.

Expressions for the confidence bands for the regression model were derived and applied to a validation test with one of the sub-basins. Relatively good results were obtained.

Previous studies have shown that the FDC approach is a useful tool for solving certain type of problems related to water resources planning. Some of the issues that have been addressed with this approach are streambank erosion and river sedimentation. Therefore, FDCs can contribute to the attainment of the objectives of the DEC plan for the Yazoo River Basin in Mississippi.

A wealth of data exists for Goodwin Creek. Further research can make use of this information to develop more complex models that can adequately account for the effect of causative variables in a manner that would be difficult to achieve in most other locations. Of particular interest in this regard, with respect to the Goodwin Creek sub-basins, would be the study multivariate hydrologic models.

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